Long term performance monitoring of ASCAT-A

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Abstract

The Advanced Scatterometer (ASCAT) on the METOP series of satellites is a six beam, real aperture, vertical polarised, C-band radar designed primarily to provide global ocean winds for assimilation into numerical weather prediction models. Its dense coverage also makes it useful for near real time use by operational weather forecasters. The basic measurement provided by the ASCAT is the normalised radar cross section (NRCS) for which other important applications have emerged in recent years over land and sea ice areas, where it provides information on parameters such as soil moisture, snow and ice properties [Figa-Saldaña et al 2002, Klaes et al 2007].

Seven years after the start of the ASCAT mission, a reprocessing of the full mission is taking place and a long-term analysis of instrument performance and product quality is being carried out, covering instrument health events and trends as well as an evaluation of calibration accuracy and stability. This assessment is important in order to evaluate the long term data record of geophysical parameters derived from the ASCAT measurements.

METOP-A was launched in 2006 and METOP-B in 2012. Dual operations of METOP-A and B are the current baseline and this situation is reviewed yearly with regard to the health of platform and instruments. The next satellite in the series, METOP-C, will be launched 2018 and is expected to operate until 2022.

INTRODUCTION

Three ground transponders are used to accurately estimate the ASCAT gain patterns, which allows an absolute calibration to be determined [Wilson et al 2010]. A number of natural distributed targets (rainforest, sea ice and ocean) are routinely used by to validate and monitor the calibration of the NRCS [Anderson et al 2012, Verspeek et al 2010].

ABSOLUTE BACKSCATTER CALIBRATION

EUMETSAT uses three transponders located in Turkey to calibrate the ASCAT instruments. The location of these transponders is carefully selected to minimise interference and to give an optimum sampling of the gain patterns. Figure 1(left) shows one of the transponders on site.

As the ASCAT passes over the transponders, it switches into calibration mode. When the transponders detect an signal from ASCAT they transmit a signal of known strength back towards the antenna with a pre-determined delay, in order to allow for the ASCAT pulse echoes to reach the instrument before this tranponder pulse. The magnitude of the signal recieved by ASCAT varies depending on the position of the transponder in the gain pattern. Figure 1 (centre) shows an example of the calibration mode raw data from ASCAT-A, showing the signal from two transponders in each of the three beams.

The calibration procedure uses that transponder data in several steps. First, The ASCAT data containing each transponder signal is converted to an antenna gain value in the antenna coordinate system. Then a model of the antenna gain and its orientation is fitted to the set of data points. Figure 1 (right) shows, as an example, a set of transponder data fitted into an antenna gain model for ASCAT-A LEFT MID beam. The residual between data and model gives an indication of the calibration accuracy, which is currently of ±0.05 dB in gain. Finally, this estimation of the antenna gain is used to calculate the normalisation factors that allow converting raw echo measurements into NRCS.

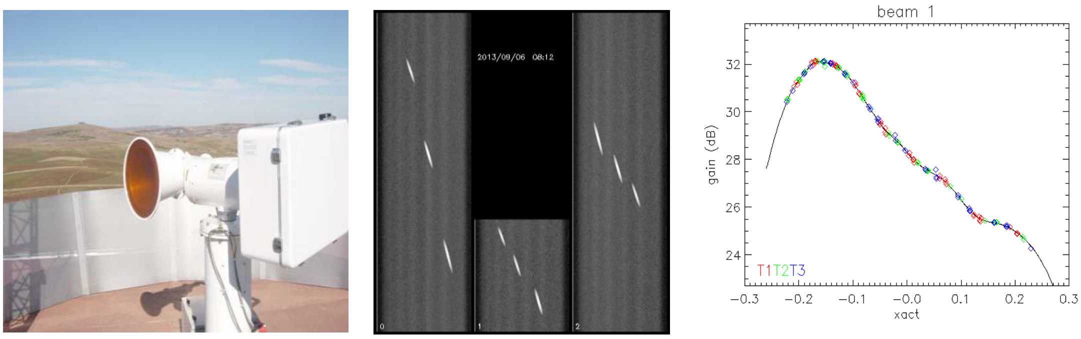

Figure 1: (left) Tranponder on site in Turkey; (centre) Image of raw transponder signams captured by ASCAT-A; (right) Estimation of gain from the transponders with the fitted gain model for the LEFT MID beam of ASCAT-A

Each transponder calibration campaign collects typically two months of transponder signals and provides therefore an estimation of antenna gain and pointing representative of that period.

STABILITY OF THE CALIBRATION

Three transponder campaigns have been carried out for ASCAT-A so far, providing calibration estimations for the times shown schematically in Figure 2 as yellow symbols.

The transponder calibration campaigns indicate slight changes in the NRCS, comparable to the method accuracy (less than 0.1 dB peak-to-peak in gain). As a reference, a change of 0.1 dB in the NRCS of the three beams is approximately equivalent to a change of 0.1 ms^{-1} in the retrieved wind speed. These results lead us to conclude that the ASCAT-A NRCS is very stable.

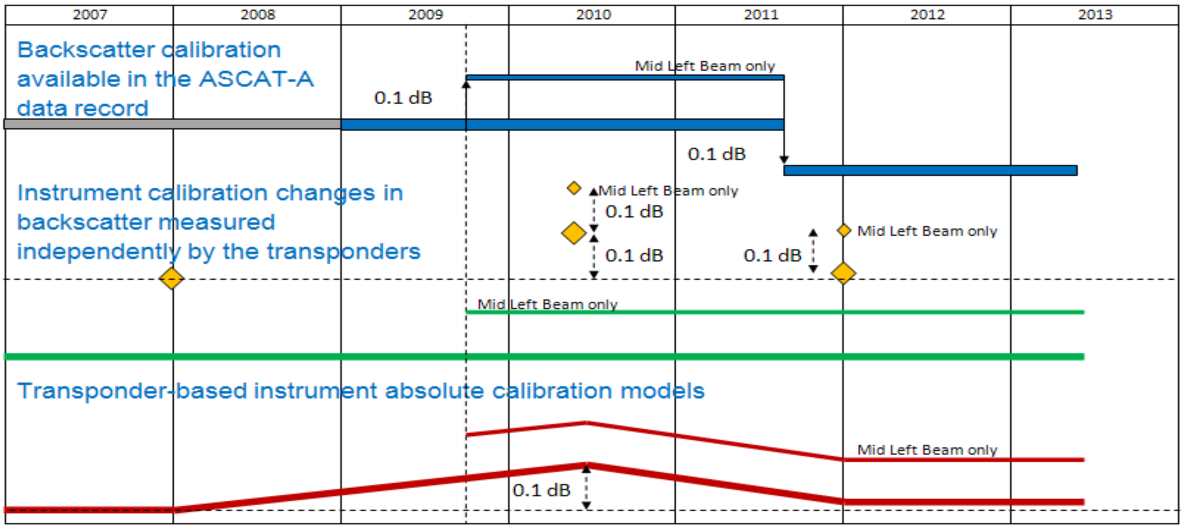

Figure 2: Schematic representation of the results of the transponder calibration campaigns (yellow). The stability of the ASCAT-A NRCS data record to date is shown in grey (representing the data already reprocessed in 2009) and continued with the near real time products record in blue. Finally, the green and red lines represent, respectively, potential ASCAT-A gain calibration stability models, based on the information derived from the available transponder calibration campaigns.

In September 2009 however, a sudden change in the LEFT MID beam calibration was detected through monitoring the near real time products. This is represented schematically in the departure of the blue lines in Figure 2. The second transponder calibration confirmed this as a change in the instrument antenna gain and the calibration configuration in the near real time processing chain was subsequently updated, as the most recent change int the blue lines in Figure 2 indicates.

The periodic estimations of the instrument calibration from the transponder campaigns can guide us in defining an instrument calibration stability model with respect to time, to be used in the reprocessing of the full ASCAT mission. Two models have been considered in this context: first, a constant calibration in time, including the detected LEFT MID beam change in 2009 (green line); second, a calibration model built through piece-wise interpolation between calibration measurement points (red line). Careful evaluation of the impact observed on the geophysical products (winds, soil moisture and sea ice) concluded that the effect was negligible (not shown). It was consequently decided to choose for the re-processing the calibration model that was simplest, both from the implementation and from the interpretation point of view, and that was the flat model.

It is planned to continue with periodic transponder calibrations of the ASCAT-A instrument (every two years), in order to extend the calibration record and to learn more about the effects of instrument ageing on the antennae gain. This knowledge will be essential in the choice of calibration model for future re-processing efforts, as well as in assessing potential sudden changes in the instrument, such as those occurred in September 2009.

TIME SERIES OF RAINFOREST BACKSCATTER

Over the Amazon rainforest [-70° to -60.5°] E and latitudes [-5° to 2.5°] N (area reprresented in Figure 3 (left)), the parameter $\gamma_0 = \sigma_0/\cos\theta$ (where σ_0 is the NRCS and θ is incidence angle) is found to be fairly constant with respect to time, viewing geometry and spatial location with a value of approximately -6.5 dB [Lecomte et al 1998], even if for ASCAT a gentle slope with respect to incidence angle has been detected [Anderson et al 2012], as can be observed in Figure 3 (right).

These characteristics allow examining the relative calibration of the ASCAT beams and monitoring the long term behaviour of the ASCAT calibration.

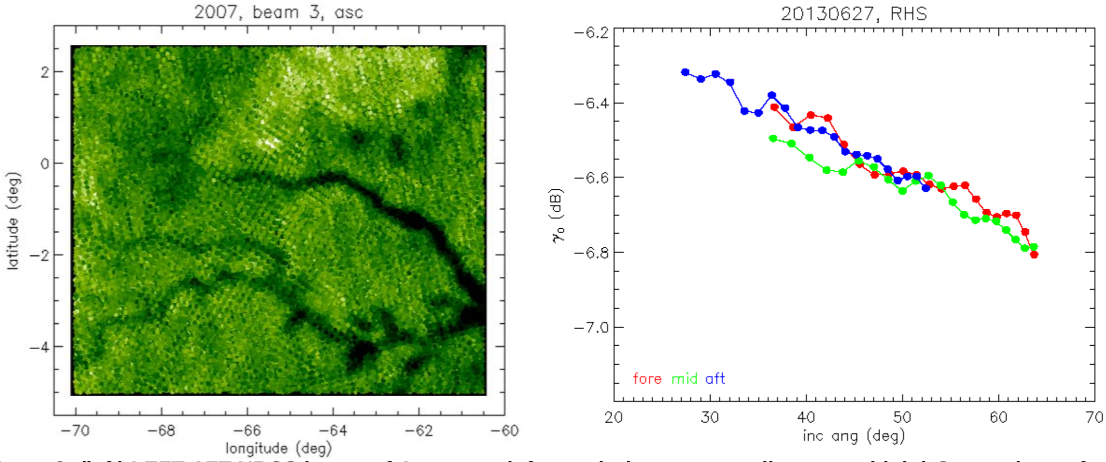

Figure 3: (left) LEFT AFT NRCS image of Amazon rainforest during an ascending pass; (right) Comparison of rainforest γ0 from the right swath beams of ASCAT-A, with respect to incidence angle.

Figure 4 shows a time series of average γ_0 per each orbit cycle (29 days) for the LEFT FORE, MID and AFT beams, based on the near real time products available to date. It clearly displays several changes, either in the instrument calibration or in the ground segment processor configuration. The first change (pointed by the blue arrow) represents the introduction of the first transponder calibration in the ground segment processor in 2008. Then we can clearly observe the change in the LEFT MID beam in 2009 (pointed by the green arrow). Finally, the update of the calibration in the ground segment processor in 2001 is visible as well (pointed by the red arrow).

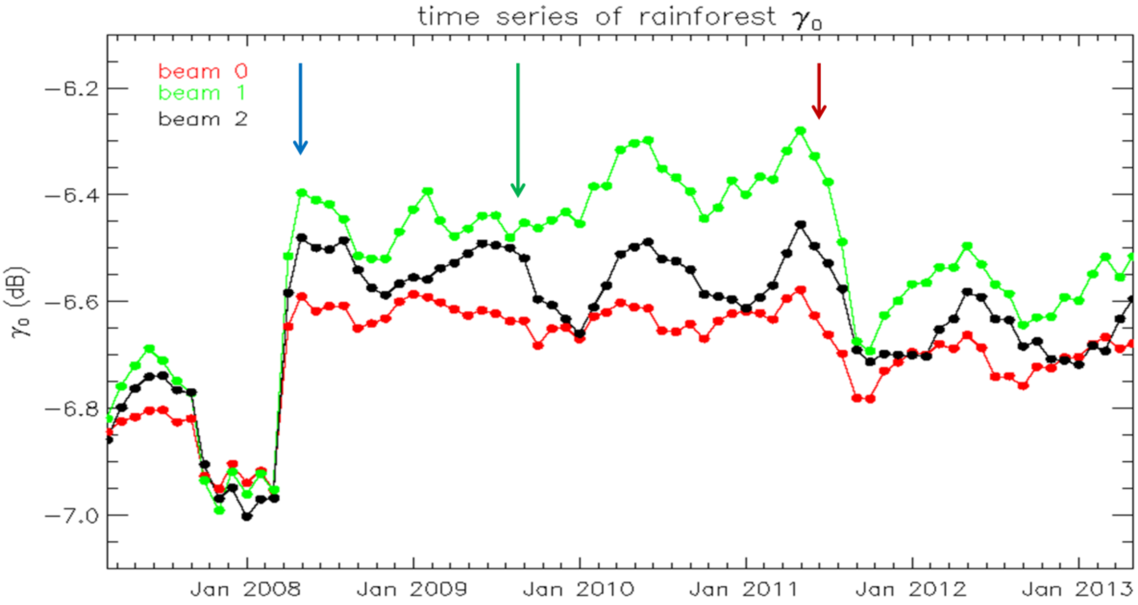

Figure 4: Time series of γ_0 over the Amazon rainforest between 2007 and 2013. Every point represents an average over a repeat orbit cycle (29 days) for ASCA-A. The time series is estimated from the near real time data record. LEFT FORE beam is represented in red, LEFT MID beam in green and LEFT AFT beam in black.

The rainforest γ_0 record in Figure 4 shows on one hand that the good calibration stability observed by the transponders is indeed confirmed over this natural target, since only known instrument changes and updates of the calibration configuration in the ground segment processor are visible. On the other hand, it also shows us the direct relation between the amplitude of NRCS calibration and the impact on γ_0. Finally, seasonal variations of γ_0 are to be noted, as expected.

TIME SERIES OF OCEAN BACKSCATTER

Any point in the ASCAT swath is observed by the FORE, MID & AFT beams, giving three NRCS measurements with different azimuth angles. When the NRCS triplets from the open ocean are plotted as points in a three dimensional space, they form a cone shape [Stoffelen 1999]. The position of the cone can be determined by taking slices through the data and estimating the location of maximum data density (Figure 5).

Changes in the cone position over time for different measurement geometries allow the behaviour of the ASCAT calibration to be monitored.

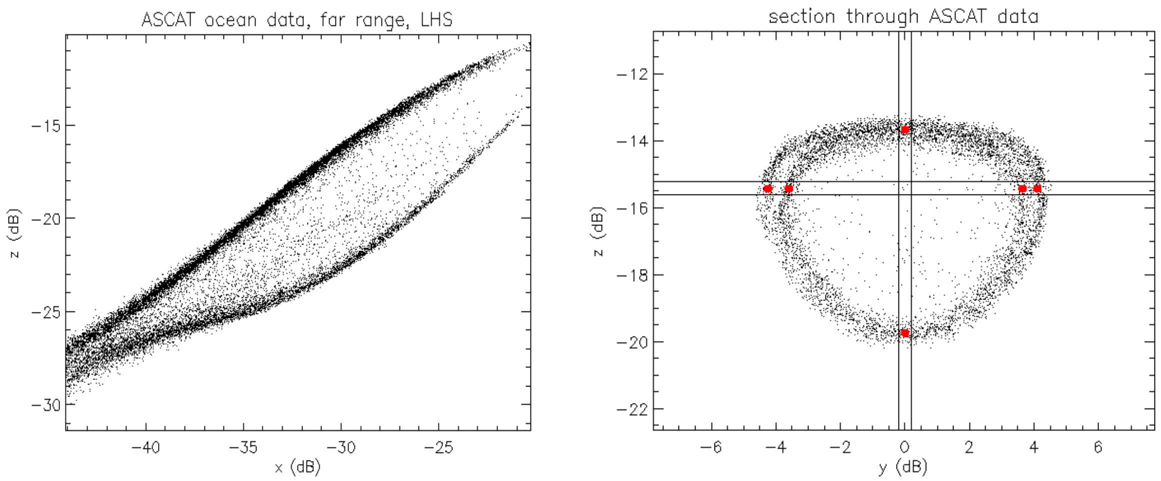

Figure 5: (left) Section along the ASCAT-A NRCS cone for a mid-swath location; (right) Section across the ASCAT-A cone for a mid-swath location. Red dots represent the location of highest density data in the vertical and horizontal slices shown in the figure. The data represented in these plots corresponds to the global oceans during a 29 day orbit repeat cycle.

Figure 6 shows the time series of these cone positions for the LEFT MID beam between 2007 and 2012. As over the rainforest, the calibration changes discussed are also visible on the ocean calibration record.

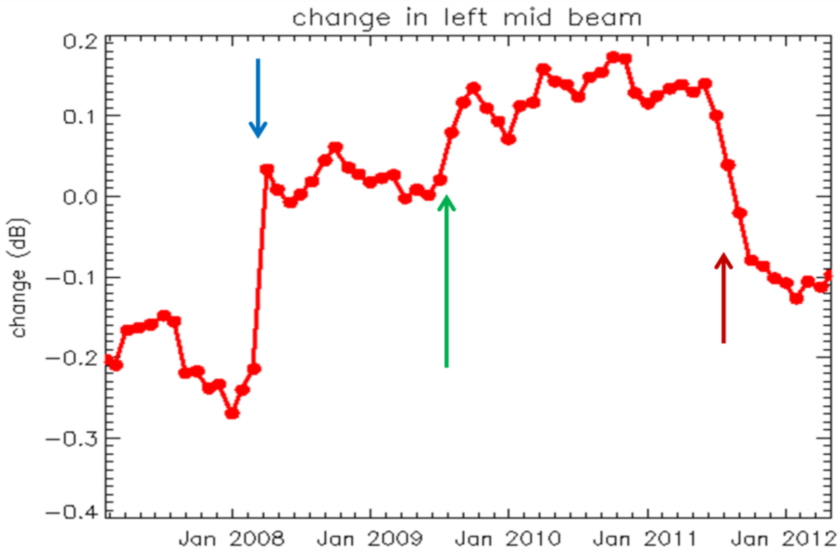

Figure 6: Time series of the ASCAT-A ocean data cone for the LEFT MID beam between 2007 and 2012. Every point represents an average over a repeat orbit cycle (29 days). The time series is estimated from the near real time data record.

As with the rainforest record, Figure 6 confirms as well the stability of the calibration over ocean and displays also the expected seasonal cycle of global winds.

RADIO FREQUENCY INTERFERENCE

As well as monitoring the instrument calibration, which is the main parameter affecting the stability of the data record, we look into several other instrument health and performance indicators. Perhaps the most interesting example is the monitoring of the ASCAT-A receiver Noise Power (NP).

After transmitting a radio pulse, ASCAT measures both the echo reflected by the Earth's surface and the background noise. Both measurements are used to estimate the NRCS. The noise measurements in particular are used to represent or model variations of the receiver gain, caused typically by changes in the thermal environment around the orbit.

Large outliers of receiver NP are occasionally found in the noise data. They most usually occur over a small number of land regions (Figure 7), which suggests that they are due to radio frequency interference (RFI) from ground based equipment. If they appeared over ocean or in small islands, they could potentially affect the estimate of ocean NRCS, particularly at low wind speeds. Over land, effects on the soil moisture record have not been observed so far, which could be related to the fact that the average NRCS over land is generally higher than over ocean.

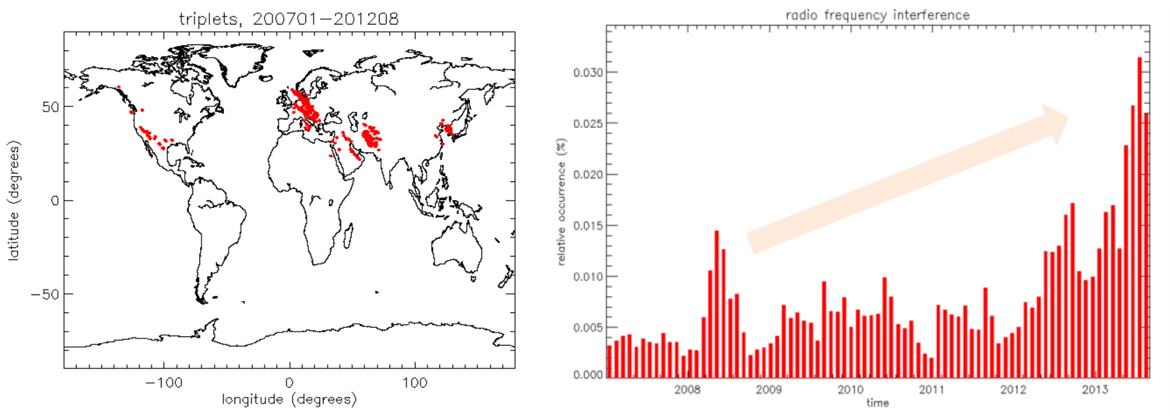

Figure 7: (left) Location of most frequent ground RFI sources observed in the ASCA-A NP values; (right) Relative occurrence (with respect to the total number of measurements) of outlier NP values over time for ASCAT-A.

In any case, these outliers are being continuously monitored and an significant increase in their occurrence in the last two years has lead to the decision at EUMETSAT to exclude these large noise values from the estimation of the instrument receive filter shape in the ground processor.

SUMMARY AND CONCLUSIONS

The long term monitoring of the ASCAT-A calibration shows a very stable instrument. The transponder calibrations show only small variations in gain. A significant observed one is the 0.1 dB mid left beam sudden change in September 2009, detected in the near real time data and confirmed by the analysis of the 2010 transponder calibration campaign. This was the driving reason for bringing the 2010 transponder calibration into the near real time ground segment processor.

The rainforest and ocean backscatter tools are very powerful in monitoring the alignment of the calibrations of the different beams, as well as the stability of the calibration in time. They show sensitivity in detecting sudden changes of about 0.1 dB in a single beam or all the beams. Slow trends in the ASCAT-A calibration are so far not evident from the rainforest or ocean time series, but it is unclear whether these natural targets are stable enough to provide an absolute calibration reference, given that their seasonal variations are of amplitude comparable with the slow instrument changes that we may want to detect or evaluate. Furthermore, it may be expected as well that they change over time with global and seasonal climate changes, which may consequently modify their backscatter response. For that reason, transponder calibration campaigns will continue to be carried out and are expected to provide more absolute calibration points to help evaluating possible trends in the data record due to instrument ageing.

The ASCAT-A instrument has still full redundancy and there are currently no signs of significant ageing. The ASCAT-A mission is operated as a stand-by to the ASCAT-B mission and it is planned that it continues providing data until the end of the ASCAT-C commissioning phase.

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